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PROFESSOR EXNER ON THE CIRCULATION OF COLD AND WARM AIR BETWEEN HIGH AND LOW LATITUDES [1]

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By ALFRED J. HENRY

[Condensed from a translation by W. W. Reed]

In continuation of his earlier work (Über die Zirkulation zwischen Rossbreiten und Pol, Meteorolog. Zeitschr., 1927, p. 46). Professor Exner now gives us the results of his studies on the subject above indicated. In the introductory statement it is pointed out that on account of the deflecting force of the earth's rotation there can not be anywhere in the hemispheres a simple circulation to carry the large amounts of heat from tropical to polar regions. The simple streaming of cold air masses toward the Equator and above this of warm masses toward the North, possible in the equatorial region, must divide as high latitudes are reached into several circulations which lie side by side on a circle of latitude. Thus on account of the rotation of the earth there can be no simple circulation oblique to a parallel; at a place on the same parallel one must expect a cold current from the polar region, beside it a warm current from the tropical region, and beside the latter a cold current again and so on.[2]

It is further indicated that in the Northern Hemisphere a warm northward flowing current can persist only when there exists a pressure gradient toward the west and in like manner a cold current from the north can persist only when there exists a pressure gradient toward the east, thus, for example if a cold current oblique to a parallel lies west of a warm current then between the two there must be a region of low pressure, and if now a cold current lies east of a warm current then there is necessarily high pressure between them so that from the number of high and low pressure regions on a parallel we may obtain the number of circulations.

Since the cyclones and anticyclones change in intensity and direction of progression from day to day, it follows that the circulations referred to do not maintain themselves in a uniform manner but continually appear to move from place to place. These currents are therefore not to be considered as constant; their manner of change from one place to another has not been determined either empirically or theoretically.[3]

The author assumes that the circulations act in a way somewhat analogous to that of a fluid, water for example, since in very large dimensions the gases through the effect of gravity become more similar to fluids than in small dimensions.

As set out in his earlier work, he looks upon them only as an effect of solar energy which produces a circulation between cold and warm regions and not as wave-like oscillations at the boundary between a region of warm equatorial air and a region of cold polar air, as the polar-front theory has designated it. In this sense the *cyclones and anticyclones are to be viewed as secondary effects of the circulation; they obtain their energy from the vigorous force of a circulation, and this vigorous force originates in the supply of heat to the lower latitudes and the withdrawal of heat from the higher latitudes.*

OBSERVATIONAL MATERIAL

In order to gain a clearer knowledge of the circulations between lower and higher latitudes Professor Exner investigated the temperature conditions at 120 stations in the Northern Hemisphere for a series of 90 days, January 1 to March 31, 1910, without a consideration of the concurrent pressure distribution. Instead of using absolute temperatures he computed the departure of the current temperature from the normal for each day of the period, and these values with proper sign attached were plotted on charts of the Northern Hemisphere. He further separated the regions of cold and warm by lines of zero departure, thus isolating the regions of positive and negative temperature departure, respectively. It was found that these regions often had the form of strips or bands oriented in a north/south direction, thus agreeing with the before-mentioned assumption. The period chosen was the year 1910, because since that time the Russian yearbooks have not appeared. The great region between Europe and eastern Asia is especially important in investigations of this character.

The winter months were chosen since the currents are more active in winter than in summer. The individual daily departures were obtained by means of a graph that showed the daily march of temperature for the year.

After isolating regions of positive and negative anomaly, respectively, those regions having departures of plus or minus 5°, 10°, 15°, and 20° C. were indicated. By reason of lack of stations in the polar regions and over the southern part of the North Pacific, the charts are incomplete for those regions.

The cold currents move for the most part toward southern latitudes and the warm currents toward the pole. It was found, however, that it was not always possible to relate every cold current to a high latitude source, as when a cold current from the north is intersected by a warm current from the south, thus permitting a remnant of the cold air mass to persist for some time until finally its temperature is raised.

The charts show that for the most part regions with departures of 10° or more C. lie in higher latitudes; it was also found that abnormally warm and abnormally cold

[1] Über die Zirkulationen kalter und warmer Luft zwischen hohen und niedrigen Breiten. Sitzungsberichten der Akademie der Wissenschaften in Wien, Abt. IIa, 137 Band, 3 und 4 Heft 1928.

[2] In many respects this concept is similar to Bigelow's counter current theory.—EDITOR.

[3] As the author points out they follow and evidently are dependent upon changes in intensity of cyclones and anticyclones however these may be brought about.—EDITOR.

currents lie often close to one another; and it is also remarked that the two kinds of currents have essentially the direction of a meridian which corresponds to the view of the circulations mentioned at the outset. In the polar regions there are almost always several meridional currents of cold and warm air, one can not therefore look upon the polar air as a cold mass continuously in repose and divided from the warm southern air by a stationary polar front, but one must assume that the cold air from the polar region flows into the tropical region and the warm currents in the opposite direction.

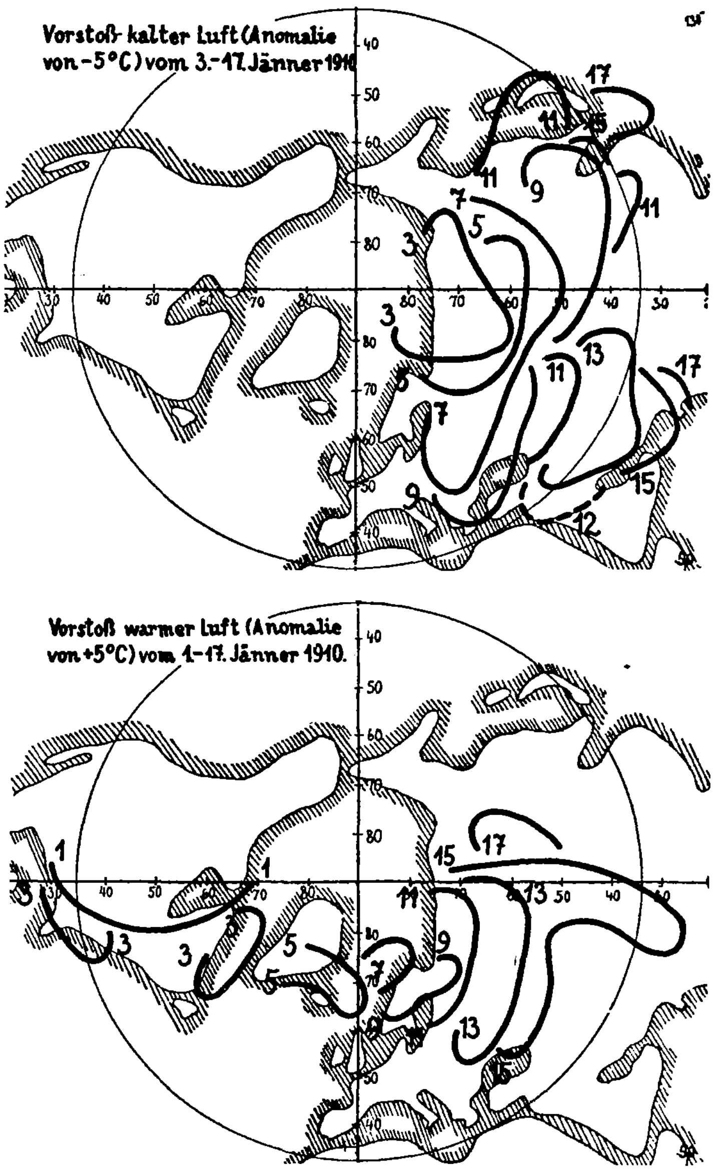
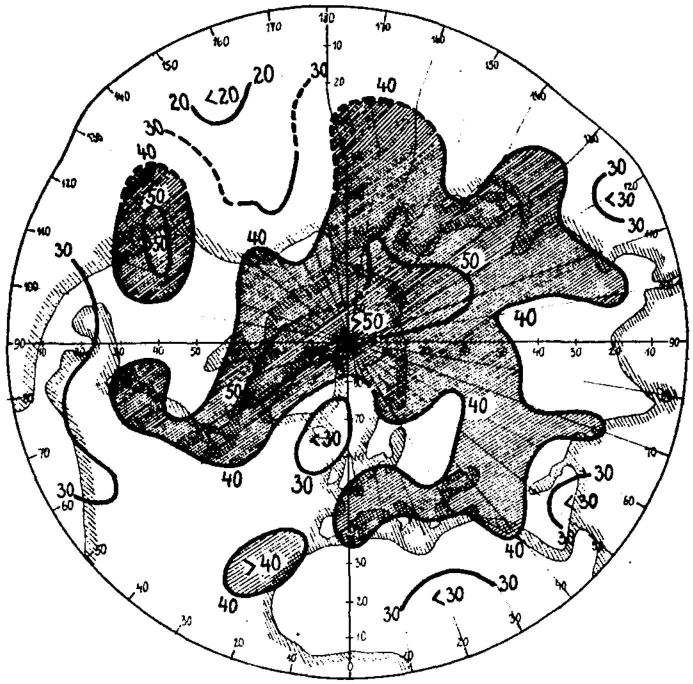


FIGURE 7.—Advance of cold air (anomaly −5° C.) January 3–17, 1910, and (below) advance of warm air (anomaly +5° C.) January 1–17, 1910

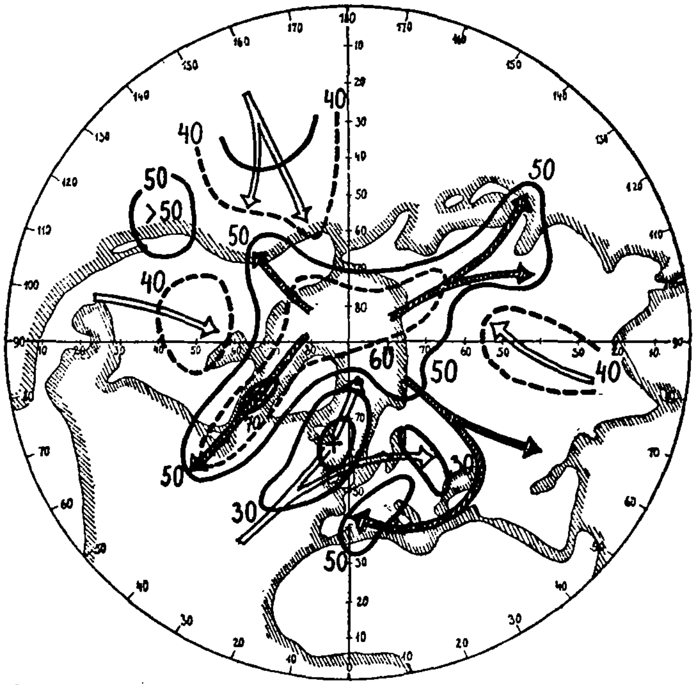
It is often noted in the charts that the warm currents have a direction toward the northeast, not directly toward the north. Also from one day to the next the zone of greatest warmth often migrates eastward; likewise the cold zones move most frequently eastward and with this they naturally have movement toward the south; they often migrate after the warm zones toward the east with the result that they are displaced more to the southward than those and thus in connection with the warm zones bring about movement in the cyclonic direction.

Occasionally there also occurs a movement of the cold zones toward the southwest. The phenomena thus manifest from the temperature charts are wholly in agreement with our knowledge of cyclones and anticyclones. If,



Häufigkeit der kalten Strömungen während der 90 Tage vom 1.I.-31.III.1910

FIGURE 8.—Frequency, in percentage, of the cold currents during the 90-day period from January 1 to March 31, 1910

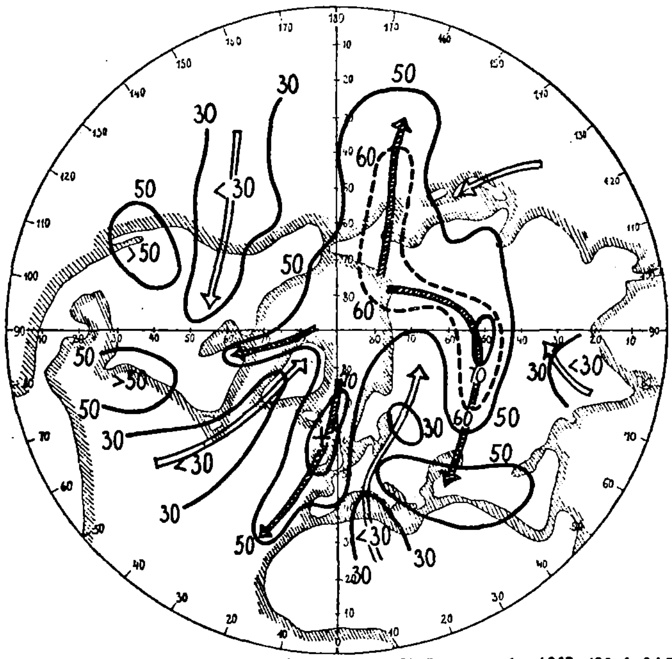


Prozentuelle Häufigkeit von „Kalt" bei Warm-Strömung unter 60°Br., 10°w.L., 49 Fälle.

FIGURE 9.—Frequency, in percentage, of "Cold" with warm current in latitude 60° N. and longitude 10° W.; 49 cases

therefore, the phenomenon of the great length of warm and cold zones exceeds the conditions for the individual cyclones and anticyclones, we have to expect that at the boundary of two currents directed essentially in the line of a meridian there occasionally form cyclones and anticyclones, respectively. In this sense one can conceive the Bjerknes idea of the "cyclone family" where several cyclones form, one behind the other, as the effect of a cold current on the west and a warm current in the east, as appeared for example in Asia on the charts for March 16–18 (not reproduced). * * *

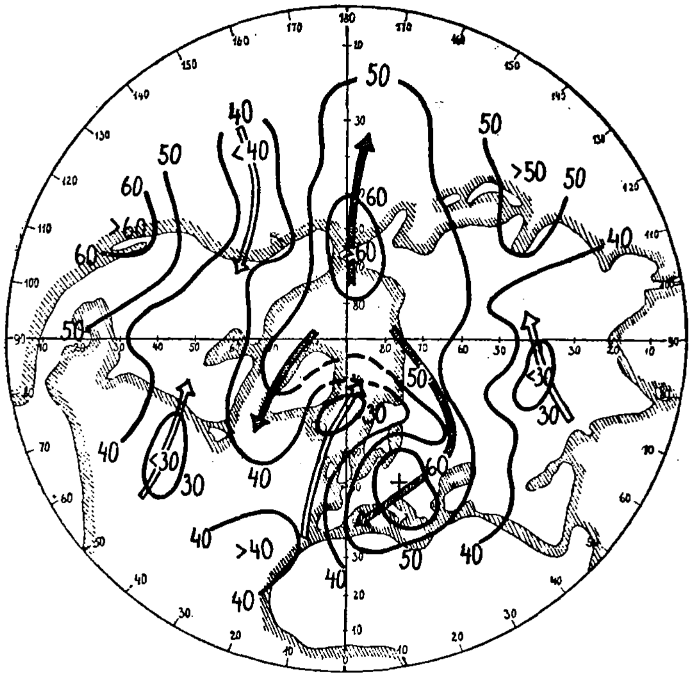
From among the 90 daily charts Professor Exner selected for discussion those of March 16–21, Figures 1–6 (not reproduced), since during these days there were marked changes in the number of circulations. In high latitudes there was seen in the beginning three circulations, then two circulations, and lastly but a single circulation. The frequency of the circulations on all of the 90 days will be discussed later; it may be remarked here that the center of the circulation, cold source to which warm currents flow and from which the cold currents flow off, must naturally not be solely in the polar regions; this would be the case if the earth had an entirely uniform surface, since in winter the pole would



Prozentuelle Häufigkeit von „Kalt" bei Kalt-Strömung unter 60°Br.,10°w.L.;31 Fälle.

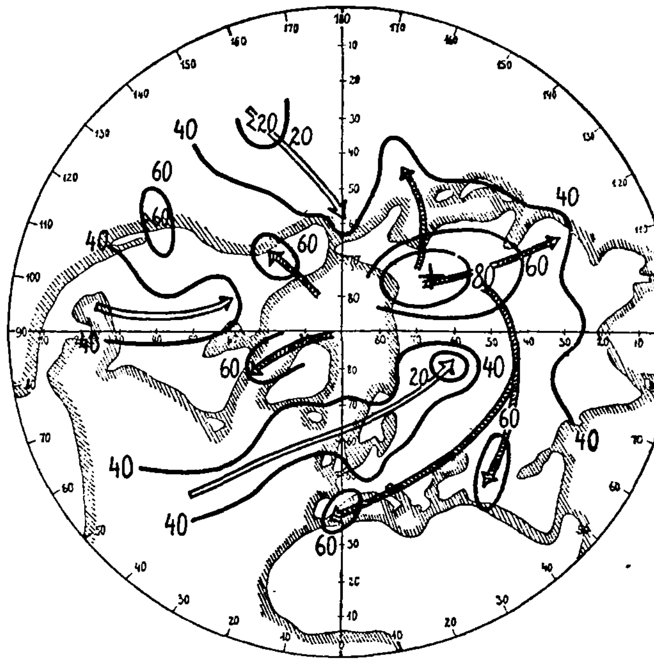
FIGURE 10.—Frequency, in percentage, of "Cold" with cold current in latitude 60° N. and longitude 10° W.; 31 cases

then be the coldest place on the earth. We must add to the region of the cold source the continental regions lying far north, the northern part of North America, Greenland, and especially northern Asia. Since in the circulation the warm currents always have the tendency to approach the region of the cold source where through radiation the air pressure falls aloft, so not only the pole is to be looked upon as the direction of the warm currents and the center of the circulation, but, for example, also northern Asia whither in Figures 1–6 the warm currents of eastern Europe gradually drift. As an example of such current phenomena Figure 7 (original numbering is followed) is presented. This figure shows the outspreading of a mass of cold air from northern Asia and the inflow into this cold region from January 1 to 17. Here are given the lines of temperature anomaly of 5° C. in the direction of movement on the Northern Hemisphere during the 17 days, and the cold and warm currents are represented separately on two charts. The upper chart of Figure 7 shows the outspreading of the cold mass. On January 3 the line of −5° C. lies in northern Asia. In the following days up to the 7th it spreads toward south, southwest, and southeast (the



Prozentuelle Häufigkeit von „Kalt" bei Kalt-Strömung unter 50°Br.,20°ö.L.;50 Fälle.

FIGURE 11.—Frequency, in percentage, of "Cold" with cold current in latitude 50° N. and longitude 20° E.; 50 cases



Prozentuelle Häufigkeit von „Kalt" bei Kalt-Strömung unter 60°Br.110-130°ö.L.;38 Fälle.

FIGURE 12.—Frequency, in percentage, of "Cold" with cold current in latitude 60° N. and longitude 110°–130° E.; 38 cases

charts give the position of the lines every other day). On the 9th the cold current begins to separate into two parts; the one migrates toward southeastern Europe and the other toward eastern Asia. The first current turns back from the west and moves toward the south, it reaches the Red Sea on the 13th and northern India on the 15th. The second current separates on the 11th into two parts of which one stretches toward the east (Japan) and the other toward the south (South China). Later the cold current concentrates between the two parts and moves toward the southeast, where on January 17 it reaches the latitude of 20° south of Japan.

The lower part of Figure 7 presents the migrations of warm air masses, which at about the middle of the month reached the region which one week earlier was abnormally cold. In an inspection of earlier charts it was manifest that this warm current, more exactly the line of anomaly of plus 5° C. emanated from eastern North America. This warm current of January 1 divided on January 3 into two parts, one of which moved to the southeast and the other to the northeast. From the 3d to the 7th the northern part, crossing over the North Atlantic, traveled to northern Scandinavia, from which position the original northeast direction became essentially an east direction. Then on the 9th and 11th the warm mass flowed in the direction of southeast to northern Asia. Here it wandered between the cold currents that had divided shortly before, advanced rather exactly toward the south (January 15) and then on the 17th moved again toward the east. Thereafter the line of +5° C. anomaly was lost, just as the two lines of −5° C. anomaly, in the Indian Ocean and south of Japan, also disappeared after the 17th. This characteristic process shows how the cold mass [apparently] draws to itself the warm mass. The invasion of the warm mass takes place here from the north and northwest, respectively; at the middle of the month the center of this circulation lies far in the south of Asia. Gradually there takes place an equalization of the temperatures of the two currents through admixture, wherewith the energy of the circulation ends. Figure 7 is the only example of this process that is reproduced. They are, however, of great variety, and it will require very accurate investigation for one to be able to judge [the value of] such process for weather forecasts. * * *

FREQUENCY OF COLD AND WARM CURRENTS

The frequency of warm and cold strips was calculated in several ways. On any parallel the number of regions having above-normal temperature is naturally identical with the number of regions having below-normal temperature. There occur across a parallel always the same number of warm and cold strips; a pair of them, a double strip forms a circulation. Whether a warm strip is wider than a cold strip will be considered later.

The number of times a circulation strip occurs on the several parallels is shown by Table 2 below. (Table 1 omitted.)

TABLE 2.—*Frequency of circulations over different latitude circles*

Latitude	Number of circulation strips							
	1	2	3	4	5	6	7	Sum
°								
70	10	**51**	28	1	0	0	0	90
60	1	19	**57**	11	2	0	0	90
50	1	6	32	**41**	9	1	0	90
40	0	8	25	**37**	19	1	0	90
30	0	7	20	**32**	20	11	0	90
20	0	1	14	29	**32**	12	2	90
Sum	12	92	176	151	82	25	2	540

In latitude 70° two circulations appear most frequently, in latitude 60° three circulations, in latitude 50°, 40°, and 30° four circulations as may be seen from the table.

The frequency distribution of the circulation strips in a given latitude can be used to estimate how wide on the average is a circulation strip. The circumference of a parallel $U = 2r\pi \cos \phi$ (r = radius of the earth; ϕ = latitude) divided by the number of circulation strips gives the width. But since the number of circulation strips is rather different on the 90 days we obtain a most advantageous idea if we evaluate the frequency of the different strip numbers in percentages. We apply for the latitude B of a circulation strip the following equation which according to Table 2 holds for latitude 70

$$B = \frac{u}{90}\left(\frac{10}{1} + \frac{51}{2} + \frac{28}{3} + \frac{1}{4}\right)$$

In this way there result for the different latitudes the following width of circulation strips:

	Kilometers		Kilometers
Latitude 70°	6, 900	Latitude 40°	8, 700
Latitude 60°	7, 240	Latitude 30°	9, 200
Latitude 50°	7, 660	Latitude 20°	8, 800

The width of the circulation strips increases somewhat toward the south, since as is well known the winds are not so strong in lower latitudes as in higher latitudes.

A cyclone or anticyclone forms in higher latitudes between a warm and a cold current strip. The average width of the cyclone was given by Hann as 2,000 to 3,000 kilometers. We can assume the double width of the cold and warm current in middle latitudes to be 7,000 to 8,000 kilometers. Therefore the cyclone region comprises only about one-third of these currents from both directions, and thus consists only of the innermost part of this circulation, as Bigelow has shown by diagram.

AMOUNT OF TEMPERATURE DEPARTURES

I have calculated, says Professor Exner, the frequency of the occurrence of regions with ±5° and ±10°, respectively, for different latitude zones from the 90 daily charts. As already mentioned, lines of ±5° and ±10° are entered on the charts. In Table 3 there is given, for example, how often during the 90 days only one region with anomaly greater than ±5° occurred on a latitude zone, in addition, how often two, three, or more regions lie in the same zone of latitude. The column to the right of these frequency numbers gives the total of all such regions which are to be found in a zone of latitude during the 90 days.

TABLE 3.—*Frequency of regions of anomaly of ±5°, ±10°, respectively, in different latitude zones*

Latitude	Number of occurrences of anomaly, regions									
	1	2	3	4	5	Sum	1	2	3	Sum
	>5°						>10°			
>70	**47**	31	5	0	0	124	28	7	0	42
70–60	12	**56**	18	4	0	194	**45**	**16**	2	**83**
60–50	7	30	**36**	**15**	2	**245**	42	11	3	73
50–40	11	45	28	5	1	210	35	5	1	48
40–30	39	35	10	1	0	143	16	0	0	16
30–20	42	24	1	1	0	97	2	0	0	2
	>−5°						>10°			
>70	41	34	5	0	0	124	32	4	1	43
70–60	18	41	25	5	0	195	40	**16**	0	72
60–50	15	38	**29**	6	0	**202**	37	5	1	50
50–40	28	33	19	6	0	175	20	1	0	22
40–30	**52**	14	6	1	0	102	12	0	0	12
30–20	33	10	0	0	0	55	6	0	0	6

These totals give for the regions with anomaly over 5° or more, the greatest frequency in the latitude zone between 60° and 50°; this great frequency extends in similar manner up to 70° and southward to 40°.

The anomalies of greater intensity (more than ± 10°) occur most frequently in the region between 70° and 60°. They have one-third to one-fourth the frequency of those of ± 5°.

The total number of warm anomaly regions is somewhat greater than that of the cold anomaly regions. This rests on the fact that in higher latitudes cooling is for the most part more intense than warming; the greater number of the smaller positive anomalies gives approximately the same departure from the previously mentioned curve of temperature march as the smaller number of large negative anomalies.[4]

DISTRIBUTION OF COLD CURRENTS OVER THE NORTHERN HEMISPHERE

In order to determine in what way current distribution of cold and warm air masses in the Northern Hemisphere depends on the distribution of continents and oceans, thus on location, the author counted the frequency of the occurrence of negative anomalies for a great number of places in the hemisphere from the 90 daily charts. For this there were used 36 points 0°, 10°, 20° . . . . 170° east longitude and 10° 20°, ... 180° west longitude and for the latitudes 70°, 60°, 50°, 40°, 30°, and 20°. Thus there resulted for each of these places a number of which shows how often in 90 cases the temperature anomaly is negative.

TABLE 4.—*Frequency of negative anomalies*

Latitude	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°	110°	120°	130°	140°	150°	160°	170°	180°
	East half																		
°																			
70	30	37	40	41	39	48	45	41	42	45	50	54	53	51	53	52	46	45	----
60	29	37	38	34	32	39	41	39	41	45	46	54	48	52	44	43	44	49	----
50	43	41	50	31	36	47	43	44	44	46	37	46	47	42	44	45	49	44	----
40	48	37	44	41	41	44	42	37	36	34	39	48	45	42	39	37	47	45	----
30	38	38	37	37	45	38	39	40	33	36	38	39	42	42	40	39	44	45	----
20	32	31	26	31	40	30	32	42	37	35	43	40	29	43	41	39	38	36	----
	West half																		
70	---	28	31	36	41	44	50	58	56	49	50	46	49	47	44	48	44	43	44
60	---	31	28	34	38	45	52	48	40	41	39	37	44	45	41	31	37	42	44
50	---	37	32	37	41	45	42	38	37	37	35	33	35	33	38	29	31	36	43
40	---	36	37	30	31	41	40	37	41	37	37	51	45	35	30	27	28	33	40
30	---	35	45	38	33	33	33	43	41	34	39	45	57	45	34	23	23	33	40
20	---	35	39	42	37	31	30	35	36	27	25	35	37	48	30	17	18	22	33

The difference of this frequency relative to 90 then gives approximately the positive anomalies, thus the warm currents. To be sure it not rarely happens that a zero line on the daily chart passes through a selected point or very near it. These cases are to be considered as either positive or negative; their frequency amounts, it is estimated, to ten times in 90 cases. If this amount is subtracted from the difference mentioned there is obtained a better, although not entirely certain result for the frequency of the positive anomalies.

The frequencies of the cases of cold are given in Table 4. Each value is related to the total of 90 (not percentages). The values in Table 4 are shown graphically in Figure 8 where the regions with frequency above 40 are shaded.

[4] Since the cyclical trend of a short period such as 90 days may be an important consideration the results of a longer period will be required to definitely determine whether positive or negative anomalies are the most prevalent.—EDITOR.

Here it is shown at once which regions of the polar area cause the most frequent outrushes of cold or cold currents into lower latitudes. First of all there are the regions of Baffin Bay, between Labrador and Greenland, and of northwestern Asia (frequency over 50 in 90 days, thus over 56 per cent). In addition the regions in higher latitudes with least frequency are of importance; they give the most frequent warm currents. Here there stands first of all the region between eastern Greenland and Scandinavia, with a frequency of 30 out of 90; that is, the eastern part of the North Atlantic Ocean; the eastern part of the Pacific Ocean shows similar conditions, only the warm currents here do not push forward into high latitudes [due to geographic-barriers] as they do in the North Atlantic.

Striking features are the frequent cold currents along the east of North America to latitude 30° and likewise that along east Asia to South China, and further the cold current from northwestern Asia toward the south and then toward the west into continental Europe.

The form of this current is similar to that of the current of eastern North America, only more strongly bent. North of this cold current from the east there advances between 50 and 60° a frequent warm current from the North Atlantic through the Baltic Sea toward the continent, and in altogether similar manner the warm current from the Pacific through western North America approaches the cold current in the east.

Both at the point of the southwestward bent cold current in western Europe and at the point of that in North America there adjoins at some distance on the west side of the continent a new cold zone over the Canary Islands and over South California. In middle Asia (longitude 80° to 90°) there appears a third zone with rather great frequency of warmth, which lies between the frequent cold currents from eastern and western Asia. In addition there are found in latitude 20° at very many places frequently less than 30 out of 90; negative anomalies are much more rare in the south than in the north, as appears from Table 3.

In general, Figure 8 represents to us the basic, although only average, current forms on the Northern Hemisphere. We see an outbreaking of cold masses from the polar regions in a direction toward southwest and an invasion of warm masses into high latitudes in the direction of northeast. The latter lie principally on the eastern sides of the oceans, the invasions of cold lie to the westward of these warm currents. Only in Asia does there appear a third warm current in the continental region. When we think of the warm current from Iceland northward it is to be expected that in its circulation this current divides to the westward and to the eastward, cools in the polar region and then flows out as a cold mass toward Labrador and toward Nova Zembla, or still farther to eastern Asia. The warm current that reaches Alaska probably makes similar divisions. In a similar manner there is a division in the cold current that moves toward western Europe into a current toward the Atlantic Ocean and a current toward Africa whereby the cold is gradually dissipated in these warm regions. Therefore, neither in the polar region nor in the tropical region can we expect to find sharp division-surfaces (lines of discontinuity—*Translator*) between cold and warm currents. They are to be assumed only in the intermediate region, where neither the warm source nor the cold source plays a significant rôle, but where the cold and warm masses pass one over the other.

The author has constructed four charts (figs. 9–12) which give the frequency of cold currents on those days when, at a given place in the Northern Hemisphere, a cold or warm current prevailed. Therewith is given a statistical relation of a chosen current at a (given) place to the currents in other regions of the hemisphere. In Figure 8 it was to be seen that cold currents rarely occur in high latitudes at 10° west longitude. He therefore first selected the days on which there appears a warm current in latitude 60° and longitude 10° west; there are 49 such cases. For these calculations were made relative to how often negative temperature anomaly appears at each tenth degree of latitude and longitude, and these frequency values were reduced to *percentage* values of the 49 cases. The result of this calculation is given by lines of equal frequency in Figure 9. The selected point, with warm current only (60° N., 10° W., having frequency of cold current 0 per cent), is indicated on the chart by a cross.

From the lines in Figure 9 it is seen that very frequently a cold current exists *west* of the warm current; the maximum, over 70 per cent, lies in the same latitude at 60° west longitude, the distance of the middle of the cold stream from the middle of the warm stream is 2,780 kilometers from which there is given the approximate diameter of the cyclone normal to that region. In striking manner there appears further the frequency of cold current in eastern Asia, about half way around the earth from the first point. In the northern part of this region the frequency is over 60 per cent; thus it appears that with a warm current west of northern Europe there generally occurs a cold current in eastern Asia. A third such region appears over northwestern Canada, and a fourth, less marked, over Nova Zembla. Rather intense warm currents are found north of Honolulu toward Alaska and besides in eastern Europe. At the same time there are some regions with now a cold current (greater than 50 per cent) and now a warm current (less than 40 per cent). Thus, for example, with marked warm current in the eastern Atlantic there forms over southwestern Europe a cold zone rather than a warm zone, while over north Germany and the Baltic Sea an offshoot of the warm current moves toward the east. The arrows that are entered on the chart give a probable form of the most frequent currents. In general, we find here four warm and four cold currents which depend on the positions of the continents and the oceans.

The second case (fig. 10) concerns the frequency of cold currents in the hemisphere under the condition that at the same place that is mentioned above (60° N., 10° W.) not a warm but a cold current prevails. For this there are found out of 90 days only 31. At the point marked by the cross the frequency is 100 per cent. This cold current in the east of the Atlantic Ocean goes far to the south. There is found connected with it frequent cold current in middle Asia (greater than 70 per cent), to the east of Asia (greater than 60 per cent), and in addition in 80° west longitude. At the same time there lie between these currents three zones with frequent warm current (cold less than 30 per cent), west as well as east of the main cold current, in the western part of the Atlantic and from Africa to northeastern Europe. The third reaches from the eastern part of the Pacific to North America. In addition there are individual smaller zones with greater or lesser frequency, which may be in part plainly connected with the main currents. If we compare the arrows of Figure 10 with those of Figure 9 we find many similarities, substantially a shifting of the currents of Figure 9 toward the east. The outbreak of cold air from Asia toward the southwest appears in both figures, likewise the tendency of the warm current in Europe toward northern Russia and the tendency of the warm current in the Pacific toward the west of North America.

In a third chart (fig. 11) there is represented the frequency of negative anomalies under the condition that a cold current prevails in 50° N., 20° E. (near Vienna).

This condition occurs on 50 days, Figure 11 shows the percentage-frequency of cold; the cross indicates 100 per cent. Here we find substantially three cold currents, the first main current from northern Asia to middle Europe; the second, over Kamchatka into the Pacific Ocean; the third, over Baffin Bay and Greenland. Nowhere in the more distant regions does the frequency amount to 70 per cent. However, the lines, especially those for 50 per cent, are rather unsymmetrically developed so that there exist connections between the currents in the distant regions. An intense warm current passes over the eastern part of the Atlantic and on over Iceland and North Cape in Europe. A second current crosses North America and a third lies in Asia. A striking feature is the cold zone in California with over 60 per cent. It can not be stated whence this cold current originates. Apparently there are individual, inclosed zones of greater or lesser cold frequency occasionally connected with the cold currents, so that we can draw for them no stream arrows as normal directions.

Figure 12 shows, in conclusion, the frequency of negative anomalies under the condition that cold prevails in eastern Asia in latitude 60° and between 110° and 130° east longitude (38 cases). Here we see in the main a rather large region with over 80 per cent frequency of negative anomaly which extends with 60 per cent frequency to latitude 40°. In most striking contrast to this cold zone is a long warm current which is directed from the Atlantic toward northeast and then east to north Asia where, in latitude 70° the frequency falls below 20 per cent. This intense warm current from a rather great distance to northern Asia indicates an interesting form of circulation. When the great cold region lies not in the vicinity of the pole but in eastern Asia then the warm current from the south of the North Atlantic Ocean does not migrate toward the pole but more toward the east. In similar manner, although not so plainly, the warm current in the Pacific appears to be directed toward the northwest, that is, toward the great cold region and not, as usually (always), toward the north or northeast. Indeed, at this time there is a cold region in the northeastern part of the Pacific. In general we find here substantially three cold and three warm currents. The chief zone of cold in eastern Asia spreads out to the south and the east and probably very far to the west as is indicated by the arrows reaching to Spain.

The asymmetry of the frequency lines is very striking in these four cases, so there must exist real connection of the currents to the conditions established. However, it may be pointed out in this connection that in the course of all cases, that is, in the 90 days, there are certain regions with rather great frequency and others with rather small frequency. From this the percentage values under the four separate conditions stand out at many places always as rather great and other places as rather small, as for example, there is on all charts rather great frequency in California [5] and rather small frequency in Honolulu. Nevertheless, the frequency had to be related to the number of the separate condition-cases and not to the frequency-values of each place, since, otherwise, the rela-

[5] The frequency in California is more apparent than real. Coastal stations are used and these are subject to fluctuations of temperature due to a change in wind direction, from the ocean to the land and vice versa; moreover both January and February, 1910, were abnormally cold months in Pacific coast States.—EDITOR.

tion of the frequency of the cold currents of (at) one place to the frequency at another place would not have been expressed.

The concluding chapter of Professor Exner's work is a theoretical discussion of warm and cold currents; naturally it is almost wholly mathematical and therefore not susceptible to further abridgment.

I conclude this review with a translation of the author's final comments on the theory of warm and cold currents as discussed in Chapter V:

Naturally the constancy of the pressure gradient is only a simplified assumption, which does not hold exact in the individual phenomena. *The result of calculation indicates that the warm* current, which initially was directed northward, soon acquires a component toward the east, that thus the warm current normally maintains a deflection toward northeast.

Through this deflection the pressure gradient toward the west is increased on account of the suction effect of the mass toward the east, thus the stationary equation can come to hold again, but *the direction of movement is now shifted somewhat toward the* right. In the cold current from the north the pressure gradient eastward is diminished by acceleration of the mass toward the east, so that then also, after the beginning of a southeasterly current direction, the stationary equation can come to hold again. A theoretical calculation of these two currents and their directions has not yet succeeded, however, in conjunction with the preliminary *simple representation of the acceleration toward the east*, it may be pointed out that the warm currents actually show for the most part, a deflection toward the east of the direction of the pole, and that the cold currents after migrating from the polar region push their easterly masses, for the most part, to the east, while the western portion of the cold current proceeds, for the most part, toward the south or to the southwest and west.

Very frequently the cold current divides into two parts after it has passed the cyclonic center lying to the east. The warm currents also occasionally divide toward northeast and northwest, whereby the latter part circles the cyclone in the east (?—*Translator*). In addition to the cause given, which consists in the change of deflective force, these phenomena are naturally connected with the change in pressure gradient.

We must assume that, between the cold current in the west and the warm current in the east, the low pressure at the limiting surface is farther diminished by whirl formation (turbulence) and centrifugal force, whereby the cyclone originates (fig. 13—not reproduced—Ed.). Conversely at the border between the cold current in the east and the warm current in the west an anticyclonic whirl can come into existence.

The cyclonic whirl advances along the lines between the warm and cold currents, and, in general in the direction of the warm current. The reason for this may lie in part in the fact that on account of less friction at the ground (not so much in contact with the ground—*Translator*) the warm current has almost always greater velocity than the cold current, as has already been mentioned, and further in the fact that the warm air is lighter than the cold so that the pressure is lowered on the eastern side.

Whether the whirl movement advances at a velocity different from that of the mass, as is the case in wave movements appears not to be determined theoretically; however, according to the occasionally very great velocities of translation of cyclones it is very probably. The rapid movement of areas of pressure rise and pressure fall also argue in favor of it. The lesser velocity of anticyclones as compared with cyclones is related to the moderate value of the difference between deflecting force and centrifugal force, which are oppositely directed, while in the cyclones the sum of these codirected forces exerts a much stronger effect.

In the fixed (stationär) movement the gradient force becomes very strong in the innermost region of cyclones through the concerted action of these two forces, in the anticyclone it becomes very weak on account of the opposing functions of the two forces.

In an earlier work (*Bildung von windhosen und Zyklonen*,) Sitzungsber. d. Akad. d. Wiss., Abt. IIa, 132 Bd., 1923) I showed an experiment in which, in a rotating tub whose water was warmed at the circumference and cooled in the center, there formed cold and warm currents, from and toward the center and therewith whirls in cyclonic and anticyclonic direction.

These experiments argue in favor of the views given above, still they have not been carried out with sufficient accuracy.

When the north current undergoes a deflection toward the east, on its eastern side as a rule, and the south current also undergoes a deflection to the east, the complicated current processes arise, and then there frequently appears the tendency for one current to cut across the other, as is seen in Charts I to VI (not reproduced). In the nonparallel course of two currents it may be of importance [to note] that in convergence the velocities are increased and there occurs a pressure fall, while in divergence there is a pressure rise through lowering of wind force.

An exact investigation of these current processes is wanting, both theoretical and practical connections. Still the phenomena mentioned at the outset give the impression that *the constant variability of air movement arises from heat supply and cold supply, which produce the circulations;* in them turbulence and mixing of the masses apparently play a very complicated rôle. Phenomena that were earlier assumed to be main causes, such as precipitation and evaporation, may be of secondary importance only. Naturally the positions of continents and oceans have great influence. But from the results of this work it can not be assumed that on an entirely uniform earth surface the variabilities would fail [to appear]; *on an entirely symmetrical hemisphere numerous circulations that have no constant form are to be expected.*

In the future of meteorology the investigation of currents may, therefore, play the most important rôle.

ATLAS OF CHARTS [6]

The atlas of charts published by the Central Meteorological Service of Austria includes the charted material from which Professor Exner drew the results and conclusions set out in the immediately preceding abstract. For convenience some of the details of the chart construction are repeated.

The atlas contains 90 pairs of lithographed charts, each pair representing the pressure distribution for the Northern Hemisphere by isobars drawn for each centimeter between 72 and 79 (28.34 to 31.10 inches). The left half of the charts is used for pressure and the right half for temperature anomalies, negative areas being shaded and positive without shading. The charts are folded in the middle and when bound come within the modest compass of 13 by 10½ inches (33 by 25 cm.).

The number of observing stations, 120, even if distributed geographically to the best advantage, would be but a single station to each 820,000 square miles of the total surface area of the Northern Hemisphere. As a matter of fact, the distribution of meteorological stations is irregular, there being a closer network in Europe and North America than in Asia. For the United States there were selected but 10 stations, 2 on the Pacific coast in California, 2 along the Gulf of Mexico, 1 on the Atlantic coast, 1 on the Mexican border, and the remaining 4 were Chicago, Salt Lake City, Oklahoma, and New Orleans.

There are both advantages and disadvantages in using a small number of stations. The advantages are less labor and greater simplicity in chart construction, and the disadvantages are that the station network is of so coarse a mesh that many important details are lost. This is particularly true of temperature anomalies. A comparison of the Exner temperature anomaly charts with those for the identical period constructed twice daily in the Forecast Division of the Weather Bureau reveals the existence of a considerable number of both positive and negative temperature anomalies lying often side by side that do not appear on Professor Exner's charts. Naturally, this was to have been expected. The result is that the number of circulations as given is smaller than would have been found by the use of more complete observational material. It is also a fair inference that the broad sweep of the isobars across continents, while perfectly legitimate from the material at hand, would be materially altered with a larger number of stations. On the other hand, to have used the more complete material when and where available would have added immensely to the labor and complexity in reaching the results set forth by the author as based upon largely generalized data.

[6] Karten der Atmospharischen Zirkulation auf der Nordlichen Halbkugel Herausgegeben von der Zentralanstalt fur Meteorologie und Geodynamik.

DISCUSSION

One can not but admire the courage of Professor Exner in undertaking with the small number of meteorological stations available to discuss the elusive problem of the form, extent, and apparent movement of areas of positive and negative temperature anomaly that appear daily on weather charts for the Northern Hemisphere.

The question naturally arises, What approach to accuracy is obtained by the use of a small number of stations? The present writer undertook to compare the results for North America with the twice daily forecast charts for the corresponding period made and filed in the United States Weather Bureau Forecast Division. Naturally, because of the closer network of stations used in drawing those charts, material differences were found and some areas of positive or negative temperature anomaly came to light which the highly generalized charts of Professor Exner did not show.

In the absence of a detailed comparison of the two sets of charts it is impossible to say to what, if any, extent the general conclusions of the author might be changed.

The Weather Bureau charts present the departures from normal temperature of the current 8 a. m. and 8 p. m. temperatures (seventy-fifth meridian time). Obviously these departures would be slightly different were the daily mean temperatures considered. In any event the labor of making an accurate check of the results of the two sets of charts is prohibitive.

THE WEATHER SITUATION IN EUROPE IN THE WINTER OF 1928–29 [1]

551.506 (4)

By F. M. EXNER

In February, 1929, the cold was very abnormal over all Europe; at Vienna on the morning of the 11th there was recorded a minimum of −14.8° F., a temperature that had not occurred at that point since the establishment of the station; that is, since the year 1775. In the course of the 154 years, during which observations have been made regularly, a temperature of −4° or lower was recorded 14 times; the lowest reading previous to this year was −11.2° in January, 1850. The 14 instances of very low temperature show no regularity as to time of occurrence; no period relative to the coldest years can be determined. On the morning of February 11 the severity of the cold just above the ground was a striking feature; while the reading was −14.8° at an elevation of 2 meters, it was −25.6° a few centimeters above the surface of the snow. This lowering of temperature was caused by radiation from the snow to the clear sky. Immediately below the surface of the ground the temperature was 14°; at depths of 2 centimeters, 50 centimeters; and at 1 meter the readings were 17.6°, 28.4°, and 35.6°, respectively. In the snow and in the ground conduction of heat is rather slow, so with clear sky in winter the surface of the earth is very strongly cooled through outward radiation.

The cold of winter is, of course, mainly the result of outward radiation. Since in our winter the sun has its position south of the Equator, the duration of solar radiation and its intensity in the Northern Hemisphere are considerably less then than in summer; in the tropical region the radiation of heat from the sun is great even in winter and then exceeds the outward radiation from the earth's surface to space; that is, the tropical region has an influx of heat even in that season. The regions of our latitudes, and the polar regions especially, have, however, in winter more outward radiation than insolation and there thus results in these higher latitudes a loss in heat.

Despite this continuous loss of heat through outward radiation in winter we do not regularly have a continuous cooling, but often a stableness in temperature or even an increase therein; this is possible only through supply of heat from lower latitudes accomplished by transportation of air. Normally the western part of Europe is much warmer in winter than the eastern part; this comes about solely through the fact that in winter the transportation of air from the south takes place more actively in western Europe than it does in eastern Europe.

Hence, the main question of the causes of our phenomena of cold and heat resolves into those of the so-called circulations. In the tropical region there prevails a heat source; the air is warmed by the ground, which is heated by solar radiation. In the polar regions there prevails a cold source; the air is made cool by the ground, which is cooled by outward radiation. The result of the warming of the air in the Tropics and its cooling in high latitudes is a circulation. Aloft there is a flow of warm air toward higher latitudes and at the ground a flow of cold air toward lower latitudes.

Of course a symmetrical circulation over the whole Northern Hemisphere is precluded. The two currents can not occur in similar manner over the whole hemisphere for the reason that the rotation of the earth produces a deflecting force which causes the poleward current to undergo deviation toward the east and the equatorward current deviation toward the west. Therefore, the circulation from cold region to warm region and in the reverse direction can take place along a meridian circle only when in connection with the poleward current there lies low pressure to the west and the deflecting force of the earth's rotation is counterbalanced by the pressure gradient; in that case a current can penetrate to the Pole. On the other hand, with a current from the north, there must be present a pressure gradient toward the east in order that the cold masses may penetrate the tropical region. Thus there form between the two currents regions of high and of low pressure; for example, if a warm current flows from south to north and on its western side there flows a cold current from north to south, then between these two branches of a circulation there lies a region of low pressure, and, on the other hand, if the cold current flows on the eastern side of the warm one there lies between the two currents a region of high pressure.

Thus the cyclone and the anticyclone appear as a result of the circulation that unquestionably must result from the presence of sources of heat and cold in fluids. All air movement on the earth is made possible by heat energy. The specially intense phenomena of air movement, such as the cyclones, originate through friction between the two currents of the circulation. We may designate such cyclones friction whirls, whose axes lie not vertical but nearly horizontal. Each cyclone and each anticyclone effects, through mixing of the air, a kind of temperature adjustment with the two currents between which it lies. The main currents of the cold and of the warm air lie, however, at the sides of the true areas of the cyclones and the anticyclones and an adjustment of temperature is maintained by these two phenomena, but still not fully effected. As a result the warm air to the east of the cyclone flows still farther toward the cold region while the

[1] *Meteorologische Zeitschrift.* April, 1929.